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THE EFFECT OF PUSHING FREQUENCY ON THE KINEMATICS OF WHEELCHAIR SPRINTING

by

© CATHERINE MARY WALSH

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

PHYSICAL EDUCATION AND SPORT STUDIES

EDMONTON, ALBERTA

FALL 1986

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Supervisor

Date...OCTOBER 1, 1986.....

DEDICATION

For Wayne and Andrew -
Who made it possible for me to reach my goal.
Much love and thanks.

ABSTRACT

This study examined the influence of different pushing frequencies on the time required to cover the final 40 metres of the 60-metre indoor wheelchair sprint. The study also examined the effect of different pushing frequencies on selected kinematic parameters.

Three male and three female national and international-level wheelchair sprinters participated in the study. A multiple-time-series design using two experimental groups and a cross-over of experimental treatments was used. During the baseline period, subjects performed five repetitions of the 60-metre sprint for five consecutive days. Each subject was required to wheel in time with an auditory metronome set to his or her previously calculated, preferred pushing frequency. During the first treatment period, group 1 wheeled at a faster than baseline frequency while group 2 performed at a frequency that was slower than that of the baseline period. During the second treatment period, the treatments administered in the first treatment period were reversed.

Temporal data, which consisted of the time required to cover the final 40 metres, and every 10-metre segment within that distance, of a 60-metre sprint, showed a gradual decrease in the time required to cover each successive

10-metre segment. These results illustrated that wheelchair sprinters and stand-up sprinters demonstrated a similar pattern of peak velocity attainment. Despite the fact that the overall results of the temporal analysis suggested that frequency had no effect on the timed performances of the subjects who participated in this study, an analysis of individual performances provided support for the hypothesis that increased pushing frequency would result in increased sprinting velocities.

Cinematographical data were collected on the final day of the baseline and each of the two treatment periods using a panning technique. Each subject was filmed over a 10-metre distance in an effort to determine the effect of different pushing frequencies on the point of hand contact, the point of hand release, the magnitude of the contact arc, the pushing length and the path of the hand during the propulsion cycle. Results of the cinematographical analysis showed much variability in the manner in which the subjects responded to the different pushing frequencies. The results did however demonstrate that the treatments had an effect on both the pushing length and the path of the hand during the recovery phase of the propulsion cycle. More specifically, at the slower pushing frequency, all subjects demonstrated longer pushing lengths and hand paths that moved away from the handrim resulting in much unproductive movement. At the faster pushing frequency, shorter pushing lengths were

observed. During this treatment period, the hand remained in close proximity to the handrim.

Results of this study have provided some valuable practical recommendations for coaches of wheelchair sprinters. The study has also raised a number of questions for further research.

ACKNOWLEDGEMENTS

The author would like to thank her advisor, Wendy Bedingfield and committee members, Pierre Gervais, Robert Steadward and Jane Watkinson for providing the direction needed to complete this study.

A sincere thank you is extended to Angela Dobbe and Michael Williams for their invaluable and endless computing assistance.

Many thanks to Gord Marchiori, Karen Calzonetti, Leanne Squair and Henriette Groeneveld for their involvement in collecting the data for this study.

And finally, a special thank you to the subjects, without whom this study could not have been a reality.

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I. INTRODUCTION

"The thing that teases the mind over and over for years and at last gets itself put down rightly on paper - whether little or great - it belongs to literature."

- Sarah Orne Jewett

Running can be regarded as a prerequisite to participation in most sports and physical activities. While Dyson (1973) described the skill as simple, "instinctive and natural", running has also been acknowledged for its mechanical complexity. Dyson (1973), Hay (1973), Slocum and Bowerman (1962) and Woicik (1983) have represented running by a cycle of leg movement that can be divided into two distinct phases. That period during which the foot is in contact with the ground is generally referred to as the drive phase, while the time during which the leg swings from the hip with its foot clear of the ground is described as the recovery phase.

For the individual that utilizes a wheelchair for his or her primary means of locomotion, "wheeling" can be considered as the basic or prerequisite skill to most wheelchair sports. Just as running is frequently divided into its two component phases, the skill of wheeling has similarly been divided into phases of drive and recovery (Byrnes, 1983; Higgs, 1984; Spooren, 1981; Steadward,

1978,1979). While some descriptions of the skill have been more complex than others, all have included a "push" or "propulsive" phase, which describes the period during which the hand applies propulsive forces to the handrim of the wheelchair, and a "recovery" phase which refers to the period during which there is no hand contact and the hand is being positioned for the next push.

Although the skill of running is a prerequisite to such sports as basketball, soccer and football, it is not the sole factor responsible for successful participation. The same is true in the case of wheeling. While wheelchair basketball, rugby and volleyball require that the participant be proficient in the skill of wheeling, this skill is one of many that contribute to good overall performance. For the athlete that competes in track events however, running, or wheeling in the case of wheelchair racing, is the single most important component of the sport. Successful performance therefore depends on the proper execution of this skill.

The objective of the competitive runner is to cover a given distance in the shortest possible time (Hay, 1973). The speed at which the athlete can cover this distance has been traditionally regarded as a product of stride length and stride frequency (Doherty, 1980; Dyson, 1973; Hay, 1973; Lopez, 1982; Luhtanen and Komi, 1978), where stride length refers to the distance covered with each stride and stride

frequency describes the number of strides taken in a specified period of time.

The importance of stride length and stride frequency to the attainment of maximum speed has been well documented in the literature (Ballreich, 1976; Lopez, 1982). Differences between the stride lengths and stride frequencies of sprinters and distance runners (Yoneda, Adrian, Walker and Dobie, 1979) and specific methods for increasing running velocity in both short and long distance runners (Armstrong and Cooksey, 1983; Ballreich, 1976; Lin and Dillman, 1982) have also been studied.

If the concepts of stride length and stride frequency are applied to the skill of wheeling, speed can be regarded as the product of the distance covered by the wheelchair with each push on the handrim (pushing length) and the number of pushes per unit of time (pushing frequency). It would seem to follow that wheeling velocity can be increased through the manipulation of one or both of these factors.

Pushing length will obviously be influenced by the amount of force applied to the handrim. According to the laws of motion, the greater the total force application, the greater will be the resultant movement of the body (i.e. the wheelchair). The frequency of force application is also very important in the determination of total force production. Studies have shown (Perrine and Edgerton, 1978; Thorstensson, Grimby and Karlsson, 1976) that as the

velocity of force application increases, the amount of force that can be generated by a particular muscle or group of muscles will decrease.

The significance of force application, pushing length and pushing frequency to the attainment of maximum velocity, has not been studied in wheelchair racing. While Higgs (1984) reported variations in pushing frequencies and pushing lengths both within and between groups of wheelchair sprinters and distance racers, attempts to determine the best balance between these factors have not yet been made. Similarly, while it has been shown that stand-up sprinters typically utilize the quickest stride frequency possible (Woicik, 1983), Higgs (1984) found no significant difference between the pushing frequencies of wheelchair sprinters and distance racers who participated at the 1980 Olympics for the Physically Disabled. Walsh, Marchiori and Steadward (in press) on the other hand, found significant negative correlations between time-on the handrim and both pushing frequency and linear velocity in wheelchair sprinting on a wheelchair ergometer. Similar findings from performances on a track have however, not been reported.

Biomechanics, as an area of scientific inquiry, has recently made significant contributions to the field of physical education and sports. During the last several decades in particular (Hay, 1973; Stothart, 1980/81), there has been an upsurge of interest in the value of biomechanics

to the preparation of athletes for competition. Much of the early work in the field of biomechanics has been concerned with the descriptive study of established techniques rather than the investigation of new techniques (Ariel, 1979). This trend has also surfaced in the field of wheelchair sport. Byrnes (1983), Higgs (1984) and Steadward (1978,1979), have gone to great lengths to describe the technique of wheeling. The question of how this technique might be modified to optimize performance in wheelchair racing has however, yet to be addressed in the literature.

In studying disabled populations, two problems are frequently encountered (WatKinson and Wasson, 1984). First, large individual differences in this population make it necessary for experimental treatments to be individual in nature. Second, because the disabled population is small compared to the non-disabled population, large groups are often difficult to find. As a result, group research designs are generally not feasible.

The use of single-subject, time-series designs, in which subjects act as their own controls, has received a great deal of attention by researchers in the field of educational psychology. WatKinson and Wasson (1984) have recently advocated the use of these designs in the study of adapted physical activity. While single-subject, time-series designs have been utilized to study the effects of individualized programs of instruction on mentally

handicapped populations (Murphy, Doughty and Nunes, 1979; Wasson, 1980; Wasson and Watkinson, 1981), similar techniques have not been implemented with the physically disabled. In this study, an attempt was made to utilize a single-subject, time-series approach in the biomechanical analysis of wheelchair sprinting.

Results of studies on stand-up runners indicate that the contribution of stride length and stride frequency to maximum velocity depends on the distance over which the athlete is required to race (Armstrong and Cooksey, 1983; Ballreich, 1976; Lin and Dillman, 1982). Of the many distances in which wheelchair athletes compete, this study was concerned with the 60-metre sprint for the following reasons:

1. Sprinting is a very popular event in wheelchair competition. At the 1984 World Wheelchair Games, 196 competitors (68 women and 128 men) participated in the 100-metre event alone.
2. Sprinting represents the purest form of wheeling in which factors such as cornering, drafting and race strategy will not confound the results.
3. Sprinting is a skill in which proper technique execution is critical to a successful outcome. Due to the very short nature of the race, determination of the most advantageous method of propulsion is essential.
4. Indoor sprinting was chosen in an attempt to control for

environmental conditions. The 60-metre sprint is the longest indoor straight sprint available.

While this study required that the subjects sprint a distance of 60 metres, only the last 40 metres of the 60-metre sprint were analyzed. This distance was chosen in an effort to eliminate the effects of the start on the time required to cover the entire distance. The final 40 metres also represented that portion of the race during which both velocity and frequency remained reasonably stable.

A. Statement of the Problem

In this study, an attempt was made to biomechanically analyze the skill of wheelchair sprinting. More specifically, the purpose of the study was to examine the influence of different pushing frequencies on the time required to cover the last 40 metres of the 60-metre wheelchair sprint. The study also examined the influence of different pushing frequencies on the following kinematic parameters:

1. The point of hand contact on the handrim
2. The point of hand release
3. The magnitude of the hand contact arc
4. The linear displacement of the wheelchair resulting from each push on the handrim
5. The path of the hand during the recovery phase.

B. Limitations

The limitations which were inherent in this study can be summarized as follows:

1. The study was limited by errors inherent in cinematographical data acquisition (Plagenhoef, 1971; Winter, 1979).
2. The accuracy of the kinematic calculations was limited by the ability of the researcher to locate reference markers on the wheelchair and the wrist of the subject.
3. The accuracy of the kinematic calculations was also dependent on the researcher's ability to identify the different phases of the wheeling cycle.
4. The study was limited by the subjects' ability to adapt to a variety of pushing frequencies over the three-week experimental period.
5. During the two treatment phases of the study, the subjects were required to wheel at either a faster or slower frequency than their preferred pushing frequency. The magnitude of these changes in frequency (approximately 10%) may have been a limiting factor in the performance of the subjects.
6. The study was also limited by the fact that the settings on the auditory metronome were factory-determined and could not be selected to match exactly the calculated pushing frequency for each subject.
7. Data were collected over the last 40 metres of the

60-metre sprint. It was assumed that any kinematic changes resulting from the manipulation of pushing frequency would be evident during this portion of the total distance.

C. Delimitations

The study was delimited as follows:

1. Three male and three female elite, wheelchair sprinters participated in this study.
2. Each subject was required to wheel at three different pushing frequencies.
3. The experimental period was carried out over three weeks.
4. Right-side views of each subject were filmed.
5. Cinematographical analyses were restricted to two-dimensional analyses of motion along the saggital plane.
6. Thirteen-inch handrims were used for all subjects.

D. Definition of Terms

Wheeling - the skill of propelling a wheelchair by pushing with the hands on the handrims.

Handrim - the circular rims, attached to the rear wheels of the wheelchair, that are used to propel and steer the chair.

Hand Contact (HC) - the point at which the hand makes

contact with the handrim.

Hand Release (HR) - the point at which the hand loses contact with the handrim.

Hand Contact Angle - the angle formed by the line joining the point of hand contact with the hub of the rear wheel and the positive vertical axis.

Hand Release Angle - the angle formed by the line joining the point of hand release with the hub of the rear wheel and the positive vertical axis.

Contact Arc - the angle formed by "hand contact", the axis of rotation of the rear wheel and "hand release".

Drive Phase - that portion of the wheeling cycle that begins with "hand contact" and ends just prior to "hand release".

Recovery Phase - that portion of the wheeling cycle that begins with "hand release" and ends just prior to "hand contact".

Pushing Frequency - the number of pushes executed by the hands on the handrim in one minute.

Pushing Length - the displacement of the wheelchair from "hand contact" to the next "hand contact".

Kinematics - the branch of mechanics that deals with the motion of a body without reference to the forces acting on that body.

Saggital Plane - that plane which divides the body into right and left halves or any plane parallel to that plane.

II. REVIEW OF LITERATURE

An analysis of the skills of running and wheeling will reveal that the two skills have a great deal in common. Despite the fact that running is performed with the legs and wheeling involves the use of the arms, both skills can be described in terms of periods of drive and recovery. The following chapter will outline the findings of researchers involved in the studies of running and wheeling. The chapter will also discuss the use of single-subject, time-series design as a recent approach to the study of disabled populations.

A. The Component Phases of Wheelchair Propulsion

Just as running has been described as a cyclic action of the legs (Hay, 1973), wheeling has similarly been subdivided into component phases. Steadward (1978, 1979) was perhaps the first to describe wheeling as a function of two separate phases of movement. In his description of the cycle of arm movement utilized in wheelchair propulsion, Steadward (1979) defined the drive or push phase as the period during which the hands are in contact with the handrims. The recovery phase was described as the period during which the hands are not in contact with the handrims and are being

positioned to execute the next push.

Byrnes (1983) studied the wheeling pattern of elite physically disabled athletes and similarly noted the existence of two main phases of the propulsion cycle. The "drive phase", as defined by Byrnes (1983) was "that period during which the hand was in contact with the push-rim of the wheelchair." It began when the hand first contacted the push-rim and ended the moment the hand released the push-rim. The recovery phase referred to "that period during which the hand was not in contact with the push-rim and was moving to the next point of contact." According to Byrnes (1983), the drive phase constituted 34% of the total wheeling cycle while the recovery phase made up the remaining 66%.

The definitions presented by Steadward (1978, 1979) and Byrnes (1983) refer to the two component phases of wheeling in terms of hand contact alone. Spooren (1981), Higgs (1984) and Sanderson and Sommer (1985) expanded on this definition by introducing force application as the criterion for determining the occurrence of the two phases.

In his description of the technical characteristics of wheelchair racing, Spooren (1981) described the "push phase" as the period of force application on the handrim. The period during which forces are not applied was described as the "dead phase" or the "recovery phase". Although Spooren (1981) referred to the presence or absence of forces in his

definition of the wheeling cycle, methods for the measurement of such forces were not provided.

Sanderson and Sommer (1985) described the propulsive phase as the period during which the hands are in contact with the pushrim and there is application of force to that rim which results in an increase or maintenance of velocity of the wheelchair. The recovery phase, on the other hand, was described as the time during which the arms are brought back to a position where a new propulsive phase can begin. This definition, according to Sanderson and Sommer (1985), is more operational in nature than absolute for there could be times during the cycle when the hands might be in contact with the rim but are not applying any force. In fact, there might be times, especially at first contact, when the hand could well be moving more slowly than the wheel, thus imparting a braking force.

Higgs (1984) has provided the most comprehensive description of the skill of wheeling. In his study of the propulsion of racing wheelchairs, four phases of the propulsion cycle were identified. The first phase, which he referred to as the "initial contact phase", described the period during which the hand was in contact with the handrim but was not applying propulsive forces. The "propulsive phase" referred to the portion of the cycle during which the hand was in contact with and was applying propulsive forces to the handrim. During the third phase, or the

"disengagement phase", the hand was still in contact with the handrim but was not in a position to apply propulsive forces. The fourth and final phase, referred to as the "recovery phase", described the period during which the hand was not in contact with the handrim and was being positioned for the next execution of phase one. Though Higgs (1984) identified four distinct phases of the propulsion cycle, he reported that due to the speed of hand movement and the limitations imposed by the photographic analysis, the identification of the first and third phase was extremely difficult. His proposed model was therefore simplified to two components which included a propulsive phase (phase two) and a non-propulsive phase (phases one, three and four).

B. Stride Length and Stride Frequency in Running

According to Hay (1973), the objective of the track athlete is to cover a given distance in the least possible time. The speed at which this distance is covered can be regarded as a product of two factors - stride length and stride frequency. These two factors, according to Dyson (1973), are always interdependent. Maximum speed in running can therefore only exist when stride length and stride frequency are in correct proportion.

The importance of stride length and stride frequency to the attainment of maximum speed has been the focus of much concern in recent running literature. Lopez (1982) suggested

that increased speed can result from increases in either stride length or stride frequency. Ballreich (1976), on the other hand, identified five possible alternatives for increasing speed in sprinting events. These included increasing either stride length or stride frequency, increasing both stride length and stride frequency simultaneously, or increasing one factor while decreasing the other. In the latter alternative, the increase in one factor must be large enough to counteract the decrease in the other factor.

Comparisons of the stride lengths and stride frequencies of sprinters and distance runners (Yoneda et al., 1979) have shown great variability between the two groups. In general, it has been found that shorter races tend to induce much higher stride frequencies and stride lengths than distance races. Results of studies involving animals, as reported by Grillner, Halbertsma, Nilsson and Thorstensson (1979) have similarly shown that as speed of movement increases, the frequency of stepping and the duration or length of step also increases.

Using seven highly skilled male distance runners as subjects, Lin and Dillman (1982) searched for the optimal stride length for each selected runner at his given running velocity. Results of their investigations showed that those with longer stride lengths were more efficient in terms of mechanical work, than those with shorter stride lengths.

Ballreich (1976), using a mathematical model, demonstrated that for eight Olympic level sprinters, increases in stride frequency induced a higher mean speed and consequently a greater improvement in running time, than comparable increases in stride length. It was concluded that for top level sprinters, running velocity can be improved to a greater degree by developing stride frequency as opposed to stride length.

In a study of the biomechanical changes resulting from increased velocity, Armstrong and Cooksey (1983) found that in nine collegiate sprinters, increased stride length played a predominant role in the production of speed up to 6.8 m/sec while between 6.8 and 8.9 m/sec, stride length plateaued and stride rate rose sharply.

Arnold (1979) similarly discussed the importance of stride rate to the competitive sprinter. In an effort to minimize deceleration in sprinting, it was suggested that the stride length be shortened slightly while increasing or at least maintaining leg speed.

Of the two factors that combine to produce maximum speed in running, Lopez (1982) reported that stride length increases are easier to achieve than comparable improvements in stride frequency. According to Lopez (1982), the potential for increasing stride frequency is partially determined by a number of hereditary factors. The body structure, movement time and reaction time of an athlete may

combine to limit the degree to which stride frequency can be increased. Recent articles (Bosen, 1979; Cavanagh, Andrew, Kram, Rodgers, Sanderson and Hennig, 1985; Glaspey, 1980; Gutoski, 1974; Leierer, 1979) have shown that stride rate can be improved through various training methods. Supramaximal running velocity for example, has been utilized to increase stride rate in sprint training. Methods such as downhill running (Leierer, 1979), horizontal drawing or towing (Bosen, 1979; Mero and Komi, 1985) both horizontal and vertical drawing (Glaspey, 1980) and high speed treadmill running (Gutoski, 1974) have all been employed to attain supramaximal running speeds. As well, Cavanagh et al. (1985) used a technique whereby sprinters were required to run in time with an auditory metronome in an effort to increase leg speed.

C. Pushing Length and Pushing Frequency in Wheeling

While there seems to be general consensus in the literature dealing with running that stride frequency plays a more decisive role than stride length in maximal sprinting velocity, similar consensus has not been reported in the area of wheelchair sprinting. In fact, very few studies dealing with pushing length and pushing frequency in wheelchair racing have yet to be published.

Higgs (1984) is perhaps the only author that has reported on the variations in pushing frequencies between

wheelchair sprinters and distance racers. In his comparison of long and short distance racers, no significant difference between the pushing frequencies of these groups was found. High intragroup variance was cited as a possible explanation for this finding.

Although Higgs (1984) did not study pushing length as it is defined in this paper (i.e. the displacement of the wheelchair from hand contact to the next hand contact) he did analyze the point of contact and release of the propulsive phase of the wheeling cycle. Several differences between sprinters and distance racers were observed. In general, it was found that the sprinters started the propulsive phase later and completed it sooner than did the distance racers. This combination of later contact and earlier completion resulted in a significantly smaller contact arc for the sprinters; 130.31 degrees as opposed to 172.93 degrees for the distance racers.

In an attempt to identify those variables which contributed to the speed of the chair in wheelchair propulsion, Higgs (1984) calculated correlation coefficients. For the sprinters, wheelchair velocity correlated positively with both the percentage of time per cycle that force was applied to the handrim and to the stroke rate. On the other hand, velocity correlated negatively with the time per cycle that force was not applied to the handrim (i.e. the recovery phase). Negative

correlations between velocity and both the distance from the vertical at which the propulsive phase was started and the length of the contact arc were also found. This, according to Higgs (1984), would seem to suggest that the faster sprinters used a technique in which they made contact with the handrim later and pushed through a shorter arc than the slower sprinters. This was performed with as high a stroke rate and with as rapid a recovery phase as possible.

For the distance racers, a different pattern emerged. According to Higgs (1984), distance racers demonstrated an earlier and longer contact with the handrim as compared to the sprinters. Distance racers also demonstrated a high stroke rate and a short recovery time.

Walsh et al. (in press), studied the effect of different seat positions on maximal linear velocity in wheelchair sprinting. Nine male sprinters performed on a stationary wheelchair ergometer and while the authors found no significant difference between the means of the velocities at each of nine seat positions, significant negative correlations between time-on the handrim and both linear velocity and pushing frequency were reported. These findings, according to Walsh et al. (in press), support the notion that an increase in pushing frequency may be more critical than an increase in time-on the handrim in producing maximum force and that maximal linear velocity in wheelchair sprinting can be best achieved by shortening the

time-on the handrim and increasing the pushing frequency. These results are however, in opposition to the findings of Spooren (1981) and Steadward (1979) who maintained that in order to maximize force application, the length of the push on the handrim should be as long as possible. Neither Spooren (1981) nor Steadward(1979) however, offered data to substantiate their claims.

D. Single-Subject Time-Series Design

According to Watkinson and Wasson (1984), two problems frequently faced by researchers in the field of adapted physical activity make the design of research studies difficult. Because disabled subjects vary widely in their needs and performance characteristics, it is generally necessary that programs and treatments be individual in nature. As well, large groups of disabled individuals are often very difficult to find. As a result, the implementation of commonly used group research designs becomes virtually impossible. Watkinson and Wasson (1984) therefore suggested the use of single-subject, time-series designs as an alternate to group research designs. In such designs, subjects act as their own controls thus eliminating the need for large groups and allowing individualized treatment.

The inverted design, as described by Kratochwill (1978), is one of many time-series research designs

presently being utilized by researchers. In the inverted design, two separate subjects or groups are observed under baseline conditions until a relatively stable pattern of performance is established. The first treatment is then introduced to one subject or group of subjects, followed by the second treatment at a later point in time. The second subject or group of subjects receives the same treatments with the order of introduction reversed. Although the use of the inverted design has been somewhat limited, it has proved to be an appropriate means of testing the effectiveness of two different treatments in two subjects or groups of subjects.

Tyler and Brown (1968) employed an inverted design to compare the effects of contingent and noncontingent reinforcement on 15 court-committed delinquent boys aged 13 to 15 years. Their design represented a slight variation of the inverted design in that no baseline measures were taken. During the first 17 days, Group I received varying amounts of money which increased in proportion to scores on a multiple choice test. Boys in Group II received a fixed amount of money each day regardless of their score. The reinforcement schedules were switched on the eighteenth day. Results supported the hypothesis that test scores would be higher under contingent reinforcement on both between and within-subject comparisons.

Gottman and McFall (1972) used an inverted design to determine the reactive and therapeutic effects of self-monitoring on oral class participation. Seventeen potential high school dropouts in a special education program were assessed on three dependent variables using a multiple-time-series design with two experimental groups, four experimental periods and a crossover of experimental treatments. Results showed that self-monitoring significantly affected the subjects' rates of oral class participation and to some extent their daily grades. The subjects showed an increase in the particular response that they were monitoring (i.e. talking or no talking).

According to Kratochwill (1978), the inverted design can be conceptualized as two simultaneous single-subject, multiple-treatment designs with the order of interventions inverted or switched. In this context, it allows control of multiple-intervention interference, which threatens designs where multiple interventions occur within a single data series.

III. METHODOLOGY

"It is common sense to take a method and try it. If it fails, admit it frankly and try another."
- Franklin D. Roosevelt

This chapter discusses the methods that were utilized to collect, reduce and analyze the data obtained from the study.

A. Subjects

Three male and three female wheelchair sprinters served as subjects for this study. All subjects were national or international-level competitors who possessed a permanent physical disability involving the lower limbs and/or trunk at a point at or below the first thoracic (T1) vertebrae level. Prior to the first day of data collection, each subject was required to complete an Informed Consent Form (Appendix A).

B. Data Collection

This study utilized a multiple-time-series design with two experimental groups and a cross-over of the experimental treatments. The experimental time line, which extended over three and a half weeks, was divided into the following periods: three days for a pre-baseline period, six days for

a baseline period, six days for the first treatment period and six days for the second treatment period. The subjects were randomly assigned to groups.

Temporal Data

During the pre-baseline period, each subject was provided with a pair of 13-inch handrims and was given 30 minutes on two consecutive days to become accustomed to the new handrims. During this time, the subjects were also given an opportunity to become accustomed to wheeling in time with an auditory metronome. On day three of the pre-baseline period, each subject was asked to perform three repetitions of the 60-metre sprint with a three-minute rest between trials. Each performance was video-taped and analyzed to determine the number of pushes executed over the last 40 metres of the 60-metre distance and the time required to cover this distance. The average pushing frequency for each subject, over the 40-metre distance, was then calculated.

During the baseline period, each subject was required to perform five repetitions of the 60-metre sprint with a three-minute rest between trials, for five consecutive days. Each subject wheeled in time with an auditory metronome set to his or her calculated preferred pushing frequency. The time required to travel the last 40 metres of the sprint, and every 10-metre segment within that distance, was measured by means of a series of retroreflective controls.

The number of pushes to the nearest one-half push, executed over the 40-metre distance were manually counted. Average pushing frequencies were then calculated to ensure that each subject was pushing at the required frequency.

During the first treatment period each subject was again asked to perform five repetitions of the 60-metre sprint daily for five consecutive days. Subjects were informed that the frequency setting on the auditory metronome had been altered but they were not made aware of the direction of the change. Group 1 was required to wheel at a faster frequency (14-16 beats/min) while group 2 was required to wheel at a slower frequency (12-14 beats/min) than their calculated average pushing frequency. The increases and decreases in frequency were chosen based on the results of the pre-baseline period during which all athletes were asked to sprint at a variety of frequencies. In general, it was believed that a 10% increase or decrease in pushing frequency would be small enough to attain during a five-day treatment period yet large enough to elicit a treatment effect. Due to the fact that the settings on the auditory metronomes were fixed, the increases and decreases in frequency varied somewhat between subjects (10.14% - 11.11% and 8.33% - 9.21% respectively). Table 1 shows the pushing frequencies for each subject during each of the three experimental periods. Both the time required to travel the last 40 metres of the sprint and the number of pushes

executed over that distance were measured.

Table 1

Pushing Frequencies (And Percentage Change from Baseline Values) for Three Experimental Periods

	Subject	Baseline (Pushes/Min)	Treatment 1 (Pushes/Min)	Treatment 2 (Pushes/Min)
Group 1	1	138	152(10.14%)	126(8.70%)
	4	144	160(11.11%)	132(8.33%)
	6	144	160(11.11%)	132(8.33%)
Group 2	2	138	126(8.70%)	152(10.14%)
	3	152	138(9.21%)	168(10.52%)
	5	138	126(8.70%)	152(10.14%)

The second treatment period, which took place during the fourth week of the testing period, was initiated by reversing the treatments administered in the first experimental period; subjects who were required to wheel at a faster frequency during treatment 1 were required, during treatment 2, to wheel at a slower frequency than their preferred pushing frequency and vice versa. Otherwise, the experimental procedure was the same as in the preceding

experimental period.

Cinematographical Data

In addition to the collection of time and pushing frequency data during the baseline and the two treatment periods, kinematic data were also collected. On day six of each of the three experimental periods, the wheeling performance of each athlete was filmed. This was carried out in an effort to detect technique changes resulting from the variations in pushing frequency.

The site selected for filming was the 40 to 50-metre segment of the 60-metre straight of an indoor 200-metre track. A Photo Sonics 16mm 1PL camera, equipped with an internal timer and an Angenieux 20-120mm zoom lens was positioned on a tripod at a perpendicular distance of 19 metres from the path of movement of the wheelchair. The camera was located at the 45-metre mark and was set at a height of .71 metres with a focal length of 65 mm. This focal length provided for a 2-metre field of view. Using two lanes of the track, the center line was marked at 1.5-metre intervals as shown in Figure 1. This line was designated as the object line. To provide a non-restricted path of motion for the wheelchair, reference markers were placed on the lane lines parallel to the object line. The reference locations on the object line were sited optically from the camera station using a camera with cross hairs in its

viewing optics. Reference targets were then placed in pairs along each optical axis on the lane lines parallel to but behind and in front of the object line (Figure 1).

The camera was loaded with Kodak 7250 film with an ASA rating of 400 and was set to operate at 100 frames per second with a shutter angle of 30 degrees, exposure time of 1/1200 second and f/stop of f/2.2.

In an effort to increase the image size resulting from the large field selected for analysis, the subjects were filmed using a "panning technique" (Bedingfield, Gervais, Kollis, Marchiori and Wronko, 1982) with a reported mean error of .002 m.

Each subject was required to perform three repetitions of the 60-metre sprint with a three-minute rest between trials for each of the filming sessions.

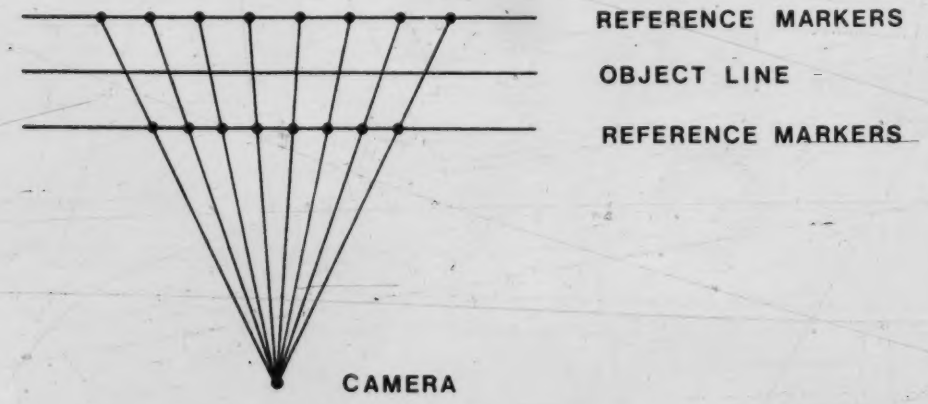


Figure 1. Overhead View of Film Set

Questionnaire

Following the completion of the final filming session, each subject was asked to complete a short questionnaire (Appendix B). The purpose of the questionnaire was to determine whether any problems were experienced by the subjects during any or all of the experimental periods.

C. Data Reduction

Temporal Data

For each day of the three experimental periods (baseline, treatment 1 and treatment 2), the fastest of the five timed trials for each subject was selected and plotted.

Cinematographical Data

Data from the filmed performances of the six subjects were obtained through the use of an electronic digitizing system. The film was projected onto a Bendix Digitizing Board using a Traid VR100 pin-registered analyzer. Film alignment was ensured by levelling the film analyzer and positioning it perpendicular to the digitizing board. The position of two wheel markers, one wrist marker and four reference markers were entered into a Hewlett Packard 9825B micro computer via a Hewlett Packard 9864A Digitizer. Data were then transferred to the mainframe computer at the University of Alberta.

D. Data Analysis

Temporal Data

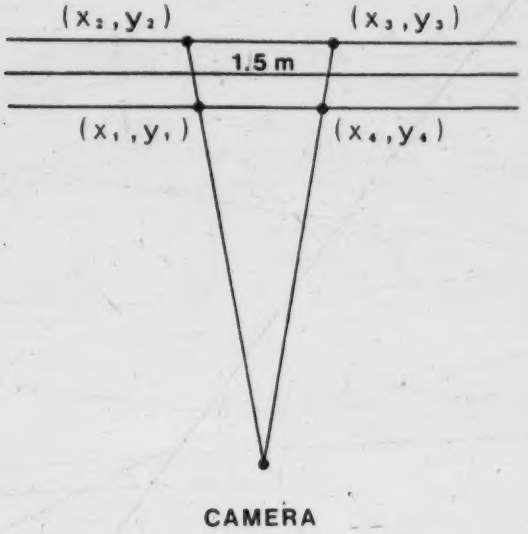
Temporal data obtained for each subject during each of the three experimental periods were plotted. Graphic analyses included analysis of baseline stability, changes in trend and variability both within and between adjacent phases, changes in level between phases and overlap between scores of adjacent phases.

Cinematographical Data

For each subject during each of the three pushing frequencies, six complete cycles of the hand around the handrim were digitized. All cinematographical calculations represent an average for those six cycles.

Calculation of Conversion Factor

The known distance between the markings on the object line was 1.5 metres. The ratio between the calculated projected image length and the actual length of this distance was used to convert the filmed measurements to real life dimensions (Figure 2).



$$Conv = \frac{1.5}{\frac{(x_3+x_4)}{2} - \frac{(x_2+x_1)}{2}}$$

where Conv = conversion factor
x_1 = x coordinate, bottom left target
x_2 = x coordinate, top left target
x_3 = x coordinate, top right target
x_4 = x coordinate, bottom right target

Figure 2. Calculation of Conversion Factor From Projected Image Length

Calculation of Wheelchair Translation

For each frame, the three subject markers were digitized (x,y) and their real life locations were calculated as follows:

$$X = Conv(x-(x_2/2)) + Ht$$

$$Y = Conv(y+Vt)$$

where x = x coordinate, subject marker
y = y coordinate, subject marker
x_2 = x coordinate, top left target
Ht = horizontal translation = 1.5 m
VT = vertical translation

Displacements were calculated using Pythagorean Theorem.

Film Speed

The film speed was calculated by using the timing marks placed on the film at 10 Hz/second by the internal light emitting diodes. For each filming session, one trial was randomly selected and the number of frames and timing marks were counted. The frame rate was calculated as follows:

$$\text{Frame Rate} = \frac{\text{Number of Frames}}{\text{Number of Timing Marks} \times 0.1 \text{ Seconds}}$$

Because film data were taken from every second frame of film, the time between frames was calculated as follows:

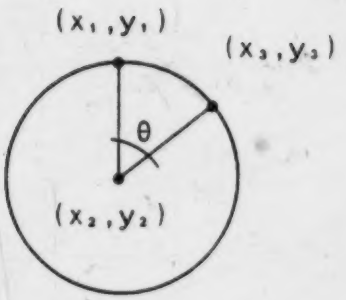
$$\text{Time Between Frames} = \frac{2}{\text{Frame Rate}}$$

Data Smoothing

Data obtained from the film consisted of X,Y position coordinates. Since there is always a certain degree of error associated with the data reduction procedure, the raw data were smoothed using a Butterworth second-order low-pass filter (Winter, 1979) with a cut-off frequency of 7 Hz.

Calculation of Hand Contact and Hand Release Angles

The angles formed by the line joining the X,Y coordinate of the wrist with the X,Y coordinate of the hub, and the positive vertical axis at hand contact and hand release were calculated using the dot product method (Anton, 1981) as illustrated in Figure 3.



$$\theta = \text{arcosine} \left\{ \frac{(x_1 - x_2)(x_3 - x_2) + (y_1 - y_2)(y_3 - y_2)}{\sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \times \sqrt{(x_3 - x_2)^2 + (y_3 - y_2)^2}} \right\}$$

where θ = magnitude of angle
$x_1 = x_2$ = x coordinate of hub
y_1 = a constant
y_2 = y coordinate of hub
x_3 = x coordinate of wrist
y_3 = y coordinate of wrist

Figure 3. Calculation of Hand Contact and Hand Release Angles

Calculation of Contact Arc

The magnitude of the angle formed by the point of hand contact, the axis of rotation of the rear wheel and the point of hand release was calculated as follows:

Contact Arc = $\theta_1 - \theta_2$

where θ_1 = hand release angle

θ_2 = hand contact angle

Calculation of Pushing Length

The displacement of the wheelchair from one hand contact to the next hand contact was calculated as follows:

Pushing Length = $X_2 - X_1$

where X_2 = position of chair at second hand contact

X_1 = position of chair at first hand contact

IV. RESULTS AND DISCUSSION

"I pass with relief from the tossing sea of cause and theory to the firm ground of result and fact."
-Sir Winston C. Churchill

The results obtained from this study are presented and discussed in the following chapter. The presentation and discussion has been divided into two main areas of focus:

1. Analysis of the 40-metre sprint times during the three experimental periods.
2. Analysis of the filmed sprint performances under each of the three experimental conditions.

A. Temporal Analysis

Results

Results of individual and mean group performances during each 10-metre segment of the 40-metre timed distance are presented in Tables 2 and 3. Scores for both groups under all three treatment conditions, show a gradual decrease in the time required to cover each 10-metre segment.

Figures 4 and 5 show the results of the daily timed performances for each subject during each of the three experimental periods. In Table 4, the mean performance

Table 2

Individual and Mean 10-Metre Segment Performances for Group 1

	20-30m (Sec)	30-40m (Sec)	40-50m (Sec)	50-60m (Sec)	Total (Sec)
Baseline					
Subject 1	1.81	1.67	1.59	1.60	6.67
Subject 4	1.89	1.78	1.73	1.70	7.11
Subject 6	1.69	1.56	1.49	1.47	6.21
$\bar{x}$(S.D.)	1.80(.10)	1.67(.11)	1.60(.12)	1.59(.12)	6.66(.45)
Treatment 1 (Increased Frequency)					
Subject 1	1.73	1.59	1.50	1.47	6.29
Subject 4	1.89	1.79	1.75	1.72	7.16
Subject 6	1.67	1.54	1.48	1.45	6.15
$\bar{x}$(S.D.)	1.76(.11)	1.64(.13)	1.58(.15)	1.55(.15)	6.53(.55)
Treatment 2 (Decreased Frequency)					
Subject 1	1.76	1.61	1.54	1.49	6.43
Subject 4	1.91	1.80	1.74	1.71	7.15
Subject 6	1.66	1.53	1.47	1.43	6.08
$\bar{x}$(S.D.)	1.78(.13)	1.65(.14)	1.62(.13)	1.54(.15)	6.55(.55)

Table 3

Individual and Mean 10-Metre Segment Performances for Group 2

	20-30m (Sec)	30-40m (Sec)	40-50m (Sec)	50-60m (Sec)	Total (Sec)
Baseline					
Subject 2	2.34	2.21	2.15	2.15	8.84
Subject 3	1.88	1.76	1.71	1.69	7.04
Subject 5	1.72	1.60	1.53	1.52	6.37
$\bar{x}$(S.D.)	1.98(.32)	1.86(.32)	1.80(.32)	1.79(.33)	7.42(1.3)
Treatment 1 (Decreased Frequency)					
Subject 2	2.31	2.19	2.13	2.12	8.72
Subject 3	1.88	1.73	1.68	1.67	7.04
Subject 5	1.72	1.61	1.53	1.51	6.37
$\bar{x}$(S.D.)	1.97(.31)	1.84(.31)	1.78(.31)	1.77(.32)	7.38(1.2)
Treatment 2 (Increased Frequency)					
Subject 2	2.24	2.11	2.06	2.05	8.47
Subject 3	1.85	1.73	1.68	1.67	6.93
Subject 5	1.70	1.57	1.50	1.48	6.24
$\bar{x}$(S.D.)	1.93(.28)	1.80(.28)	1.75(.29)	1.73(.29)	7.21(1.1)

scores for each subject are represented in terms of velocity values. These scores were calculated from the distance covered (40 metres) and the time required to cover that distance (Figures 4 and 5).

During the baseline period, the scores for subject 1 (Figure 4) displayed a downward trend. During treatment 1 (increased pushing frequency), a decrease in both the level (.38 sec), as represented by the mean score for the period, and the variability of the scores was observed. No overlap with the scores of the baseline period was seen. During treatment 2 (decreased pushing frequency), the level of the scores (6.43 sec) fell between baseline (6.67 sec) and treatment 1 (6.29 sec) values. The variability of the scores during this period increased over that of the previous period while a shift to a downward trend was observed. Only the final score of treatment 2 overlapped with the scores of treatment 1.

Subject 4 (Figure 4) displayed a great deal of variability in the baseline scores with no apparent trend in these scores. During treatment 1, less variability accompanied by a slight downward trend in the scores was observed. The level was slightly higher than that of the baseline period (.05 sec). Scores during treatment 2 were almost identical, both in level and variability, to those of treatment 1. Once again, no apparent trend was evident. Overlap between the scores of all three treatment periods

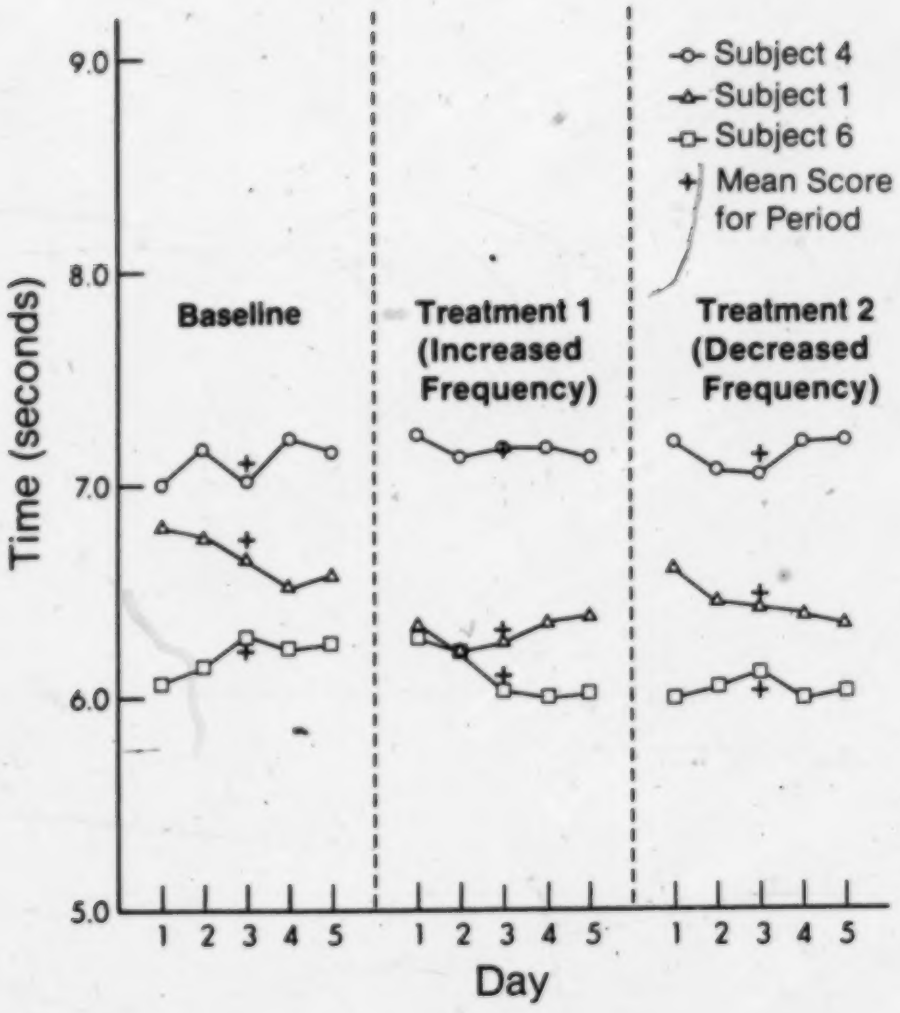


Figure 4. Daily 40-metre Times for Group 1.

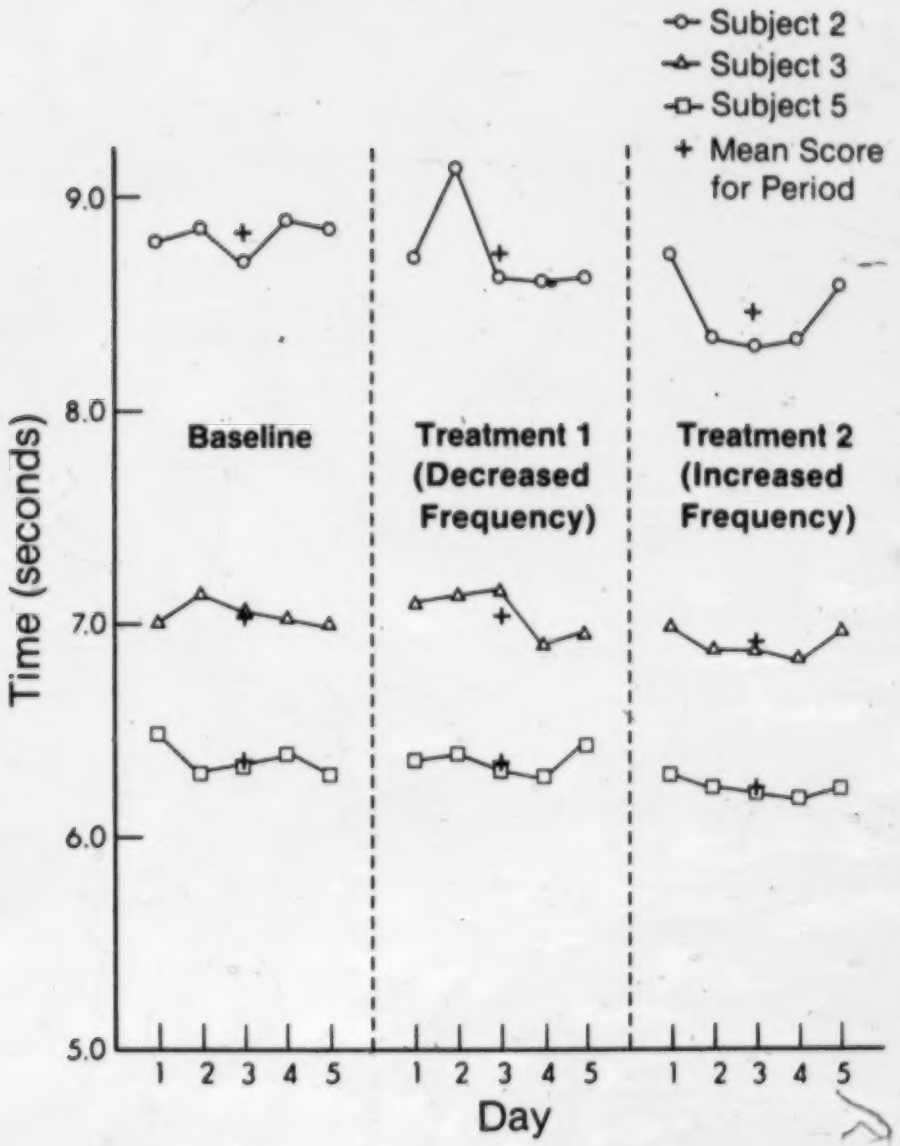


Figure 5. Daily 40-metre Times for Group 2.

Table 4

Individual and Mean Group Velocities During Different Experimental Periods

	Subject	Baseline (m/sec)	Treatment 1 (m/sec)	Treatment 2 (m/sec)
Group 1	1	5.99	6.36	6.22
	4	5.63	5.59	5.59
	6	6.44	6.50	6.58
	$\bar{x}$(S.D.)	6.02(.41)	6.15(.49)	6.13(.50)
Group 2	2	4.52	4.57	4.72
	3	5.68	5.68	5.77
	5	6.28	6.28	6.41
	$\bar{x}$(S.D.)	5.49(.89)	5.51(.87)	5.63(.85)

was observed.

Under baseline conditions, subject 6 (Figure 4) displayed a gradual upward trend in the scores. During treatment 1, the trend changed to a downward trend and the level of the scores decreased by .06 seconds. The variability of the scores during both the baseline and the first treatment period were similar with much overlap occurring between the periods. Scores during treatment 2 showed another decrease in level (.07 sec) as well as a slight decrease in variability from the scores of treatment 1. Once again, the scores of treatment 2 overlapped with

those of the previous period.

Figure 5 illustrated no apparent trend in the scores for subject 2, under baseline conditions. During treatment 1 (decreased pushing frequency), the variability of the scores increased dramatically while the level decreased by .08 seconds. Some initial overlap with the scores of the baseline period was observed. Treatment 2 (increased pushing frequency) was characterized by a variability of scores similar to that of treatment 1 and another decrease in level (.29 sec). Downward trends during both treatment 1 and 2 were observed.

Subject 3 (Figure 5), during the baseline period, displayed a slightly downward trend with little variability in the scores. Treatment 1 was accompanied by an increase in variability, a downward trend and no change in the level of the scores. During treatment 2, a decreased level was observed (.11 sec) as well as a slightly decreased variability in the scores. Considerable overlap with the scores of treatment 1 was observed.

During the baseline period, the scores for subject 5 (Figure 5) showed a slight downward trend with little variability. No difference in the level of the curves between baseline and treatment 1 conditions (6.37 sec) was observed but a slightly lower variability of scores was detected during treatment 1. Treatment 2 showed no change in variablity but did show a decrease in the level of the

scores (.13 sec) from those of treatment 1. Little overlap with the scores of the previous period was observed.

Discussion

The results presented in Tables 2 and 3 suggest that wheelchair racers are similar to runners in terms of the distance at which peak sprinting velocities are attained. According to Woicik (1983), top level runners have been found to reach peak velocities at approximately 60 yards (54.86 m) while Tables 2 and 3 indicate that wheelchair sprinters similarly reached maximum speeds somewhere beyond the 50-metre mark. Based on the decreasing time values displayed for each successive 10-metre segment in Tables 2 and 3, it appears plausible to suggest that given a 100-metre race, peak velocities for wheelchair sprinters would occur close to the 60-metre distance.

The results presented in Figures 4 and 5 suggest that on the whole, the treatments introduced during the course of this study had no effect on the timed performances of the six subjects involved. A more detailed analysis of the individual scores obtained during the three experimental periods provides additional information regarding the variations observed between subjects and suggests that under more closely controlled experimental conditions, a treatment effect may have been observed.

Under baseline conditions (Figures 4 and 5), the scores for subjects 1, 3 and 5 showed a general downward trend which suggests that, over the five-day period, performances for these subjects may have been influenced by maturation (learning). Subjects 2 and 4, on the other hand, displayed a great deal of variability with no apparent trend in baseline scores. This variability suggests that the subjects may have experienced difficulty in acquiring the skill of wheeling in time with a metronome. The fact that subjects 2 and 4 displayed the slowest times of all six subjects also implies that they were not at the same level of performance as the other athletes. Subject 6 showed an initial upward trend followed by a levelling of scores during the baseline period. It can only be assumed that confounding historical influences (eg. other training activities) may have coincided with the intervention.

In the case of all six subjects, it is believed that a longer pre-baseline period may have produced more stable baseline performance scores. At the onset of this study, it was assumed that a three-day pre-baseline period would provide sufficient time for the athletes to become accustomed to the technique of wheeling in time with a metronome. The results of the baseline period suggest that this was not the case.

While the scores observed during the baseline period appear to show a great deal of variability, this variability

did not become evident until after the implementation of the first treatment. These findings may be important to other researchers in that what may appear to be a stable baseline may in fact only be stable for a particular group. For example, while the baseline scores obtained in this study might have been stable for less experienced competitors, these same scores resulted in an unstable baseline for the elite athletes who participated in this study.

A comparison of baseline scores with those obtained during the period of increased pushing frequency (treatment 1 for group 1 and treatment 2 for group 2) illustrated that five of the six subjects showed a mean decrease in the time required to cover the 40-metre distance. The fact that there was virtually no overlap between baseline and increased pushing frequency scores for the five subjects, suggests that the treatment, as opposed to normal variations in the scores, was responsible for the results. These results support the findings of Ballreich (1976) who demonstrated that for eight Olympic level sprinters, increases in stride frequency induced higher than normal mean speeds and consequently improvements in running times. The decrease in level (.38 sec) and change in trend displayed by the scores of subject 1, strongly suggest a treatment effect. The initial downward trend in the scores of subject 2 implies that a period of adaptation to the new pushing frequency was necessary while the final upward trend may be explained in

terms of confounding historical influences (eg. time of day, daily routine of the subject). Subject 3 and 5 also displayed decreases in the level of mean scores from baseline to treatment 2 conditions. Although the decreases in level (.11 and .13 seconds respectively) were not as large as those displayed by subjects 1 and 2, they were considered to be significant based on the results of the 1984 World Wheelchair Games where the difference between a gold and a silver medal for the men's open 100 metres was .13 seconds. The results displayed by subject 6 also showed a decrease in the level of scores (.06 seconds). It is believed that this decrease may have been even larger had the frequency during treatment 1 been slightly less than that which was implemented (160 beats/min). Comments offered by subject 6 on the questionnaire which was administered following the completion of this study, indicated that this subject experienced much difficulty attaining the required frequency. Similar comments were offered by subject 4 which may explain why, during the increased pushing frequency condition, the scores for this subject were slower than those of the baseline period.

Given the preceding analysis, it is believed that all six subjects might have responded to the increased pushing frequency treatment in the same manner if the increase in frequency for subjects 4 and 6 had been smaller. As reported by Lopez (1982), frequency is partially determined by

hereditary factors and therefore its potential for increase is limited. It is possible that, under baseline conditions, subjects 4 and 6 were wheeling at a higher percentage of their maximum pushing frequency than the other subjects. The increase in frequency implemented during treatment 1 could therefore have resulted in a pushing frequency that was beyond the limits of what these two subjects could achieve.

Analysis of the results obtained during decreased pushing frequency conditions showed that for two of the subjects (subject 1 and subject 2) scores fell between those of the baseline and increased pushing frequency periods. Subjects 3 and 5, on the other hand, each displayed the same level of performance during baseline and decreased pushing frequency conditions whereas the scores for subject 6 were faster, during treatment 2, than during both the baseline and first treatment period. While it was predicted that performances during the period of decreased pushing frequency would be slower than during the baseline period, the fact that three subjects achieved better times under decreased pushing frequency conditions supports the findings of Ballreich (1976) who reported improvements in running time as a result of increases in stride length. According to Ballreich (1976) however, these improvements were not as great as those achieved with comparable increases in stride frequency. The unchanged level of performance from baseline to decreased pushing frequency conditions for subjects 3 and

5, the increased level for subject 4 as well as the overlap with baseline scores for subjects 2, 3, 4 and 5 refute any recommendation that athletes should decrease their pushing frequency in an effort to optimize sprinting times.

B. Cinematographical Analysis

Results

The effects of different pushing frequencies on the kinematics of sprinting are shown in Tables 5 and 6. For each subject, the mean angle of hand contact (HC), angle of hand release (HR), contact arc (ARC) and pushing length (PL) achieved under each of the three experimental conditions are presented.

Table 5 shows the results for group 1. During the baseline period, a great deal of variability between the subjects, in all four areas (hand contact, hand release, contact arc and pushing length) can be seen. Subject 1, for example, contacted the handrim well before subjects 4 and 6. As well, subject 1 released the handrim sooner than the other two subjects. Subject 4 displayed the largest contact arc (2.58 radians) of the three subjects, while subject 6 travelled the furthest (2.74 metres) as a result of one push on the handrim.

Table 5

Mean (Standard Deviation) Kinematic Values for Group 1 at Different Pushing Frequencies

	Baseline	Treatment 1 (Increased Freq)	Treatment 2 (Decreased Freq)
Subject 1			
HC(rad)	-.14(.12)	0.37(.11)	-.07(.13)
HR(rad)	2.25(.15)	2.47(.10)	2.99(.23)
ARC(rad)	2.39(.09)	2.08(.09)	3.03(.24)
PL(m)	2.72(.15)	2.49(.13)	2.99(.19)
Subject 4			
HC(rad)	0.11(.12)	0.14(.12)	0.23(.06)
HR(rad)	2.70(.33)	2.06(.21)	2.45(.20)
ARC(rad)	2.58(.39)	1.93(.28)	2.19(.21)
PL(m)	2.28(.08)	2.20(.27)	2.60(.03)
Subject 6			
HC(rad)	0.16(.17)	0.11(.08)	-.06(.09)
HR(rad)	2.60(.40)	2.03(.17)	3.04(.52)
ARC(rad)	2.48(.35)	1.90(.20)	3.10(.48)
PL(m)	2.74(.09)	2.59(.08)	2.99(.08)

During treatment 1 (increased pushing frequency), both subjects 1 and 4 contacted the handrim later (.51 and .03 radians respectively) than during baseline conditions while subject 6 contacted the handrim earlier (.05 radians). The angle of hand release for subjects 4 and 6 was smaller (.64 and .57 radians) than that of the baseline period. Subject 1 released the handrim later (.22 radians) than under baseline conditions. During the period of increased pushing frequency, both the magnitude of the contact arc and the pushing length were smaller for all three subjects.

During treatment 2 (decreased pushing frequency) conditions, subject 6 contacted the handrim before (.22 radians) the hand contact point of the baseline period. Subjects 1 and 4 contacted the handrim at a later point (.07 and .12 radians respectively). The hand release angle was larger for subjects 1 and 6 (.74 and .44 radians) while subject 4 released the handrim earlier (.25 radians) than under baseline conditions. During the period of decreased pushing frequency, the magnitude of the contact arc increased for two of the three subjects (.64 radians for subject 1 and .62 radians for subject 6) but decreased from baseline values, for subject 4 (.39 radians). Despite the differences between subjects in the execution of the wheelchair stroke, all subjects under treatment 2 conditions, increased their pushing lengths (.27, .32 and .25 radians for subjects 1, 4 and 6 respectively) over that

of baseline conditions.

Table 6 illustrates the kinematic results for group 2. Once again, variability between subjects was observed during the baseline period. A difference of .43 radians was seen between the earliest (subject 2) and the latest (subject 3) angle of hand contact. An even larger difference (1.27 radians) was observed between the earliest (subject 2) and the latest (subject 3) angle of hand release. Subject 3 displayed the longest contact arc (2.51 radians) while subject 5 travelled the furthest as a result of one push on the handrim (2.73 metres).

During treatment 1 (decreased pushing frequency), both subjects 3 and 5 showed an increase in the length of the contact arc (.28 and .01 radians) while subject 2 showed a decrease in the magnitude of this arc (.16 radians) as compared to that of the baseline period. The changes in contact arc size were achieved through an earlier hand contact and later hand release by subject 3 and a later hand contact and release by both subjects 2 and 5. All three subjects displayed an increase in pushing length scores over those of the baseline period (.25, .15 and .19 metres for subjects 2, 3 and 5 respectively).

The results of treatment 2 (increased pushing frequency) show that all subjects contacted the handrim later (.28, .02 and .23 radians for subjects 2, 3 and 5 respectively) than under baseline conditions. Subjects 2 and

Table 6

Mean (Standard Deviation) Kinematic Values for Group 2 at Different Pushing Frequencies

	Baseline	Treatment 1 (Decreased Freq)	Treatment 2 (Increased Freq)
Subject 2			
HC(rad)	-.03(.08)	0.17(.15)	0.25(.11)
HR(rad)	1.65(.12)	1.73(.08)	1.53(.13)
ARC(rad)	1.72(.06)	1.56(.14)	1.33(.20)
PL(m)	1.89(.05)	2.14(.07)	1.78(.12)
Subject 3			
HC(rad)	0.40(.08)	0.20(.08)	0.42(.06)
HR(rad)	2.92(.57)	2.98(.38)	2.45(.36)
ARC(rad)	2.51(.53)	2.79(.40)	1.95(.38)
PL(m)	2.35(.14)	2.50(.08)	2.14(.07)
Subject 5			
HC(rad)	0.05(.33)	0.17(.14)	0.28(.13)
HR(rad)	2.36(.29)	2.45(.19)	2.47(.14)
ARC(rad)	2.24(.34)	2.25(.16)	2.17(.15)
PL(m)	2.73(.17)	2.92(.44)	2.53(.17)

3 released the handrim earlier (.12 and .47 radians) while subject 5 displayed a later hand release (.11 radians) during this period. The result of these changes in hand contact and hand release was a smaller than baseline hand contact arc for all three subjects. The distance travelled as a result of one push on the handrim was also smaller than baseline values for all three subjects (.11, .21 and .20 metres for subjects 2, 3 and 5 respectively).

Figures 6 and 7 show the path taken by the hand during one complete cycle of the handrim for subjects 1 and 5. The results for these subjects are representative of the results displayed by the entire group. The graphic illustrations presented in Figures 6 and 7 indicate the periods of hand contact and hand release (as represented by the wrist coordinate values) during the propulsion cycle for each of the three experimental periods.

Under baseline conditions, between-subject variability in the path of the hand during the recovery phase was observed. While subject 1 displayed a path which maintained close proximity to the handrim throughout the entire recovery phase, the path taken by subject 5 showed large deviations from the handrim, especially in the final portion of the cycle.

During the period of increased pushing frequency, all subjects, as demonstrated by subjects 1 and 5, displayed a path that was closer to the handrim than the path of the

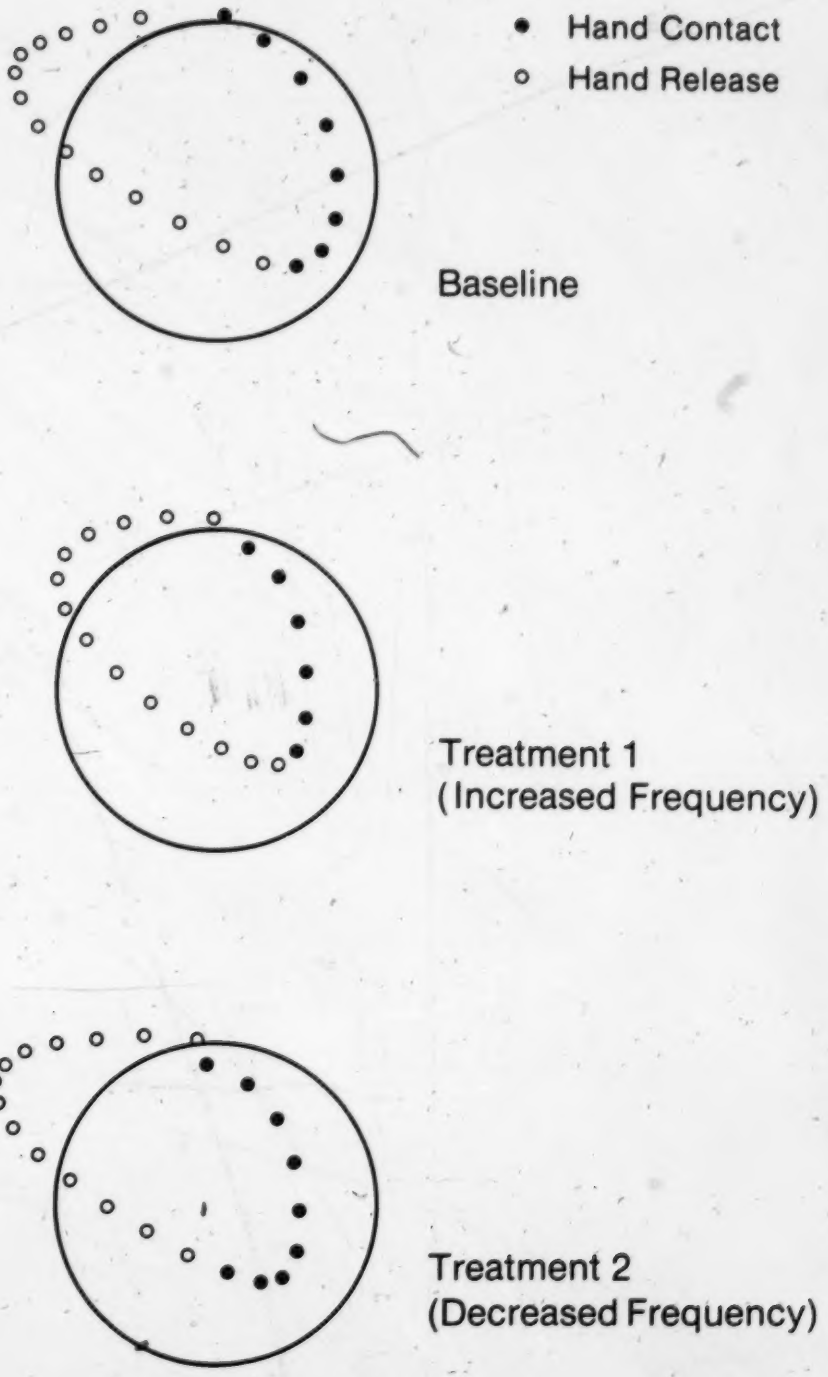


Figure 6. Hand path for subject 1 during three experimental periods.

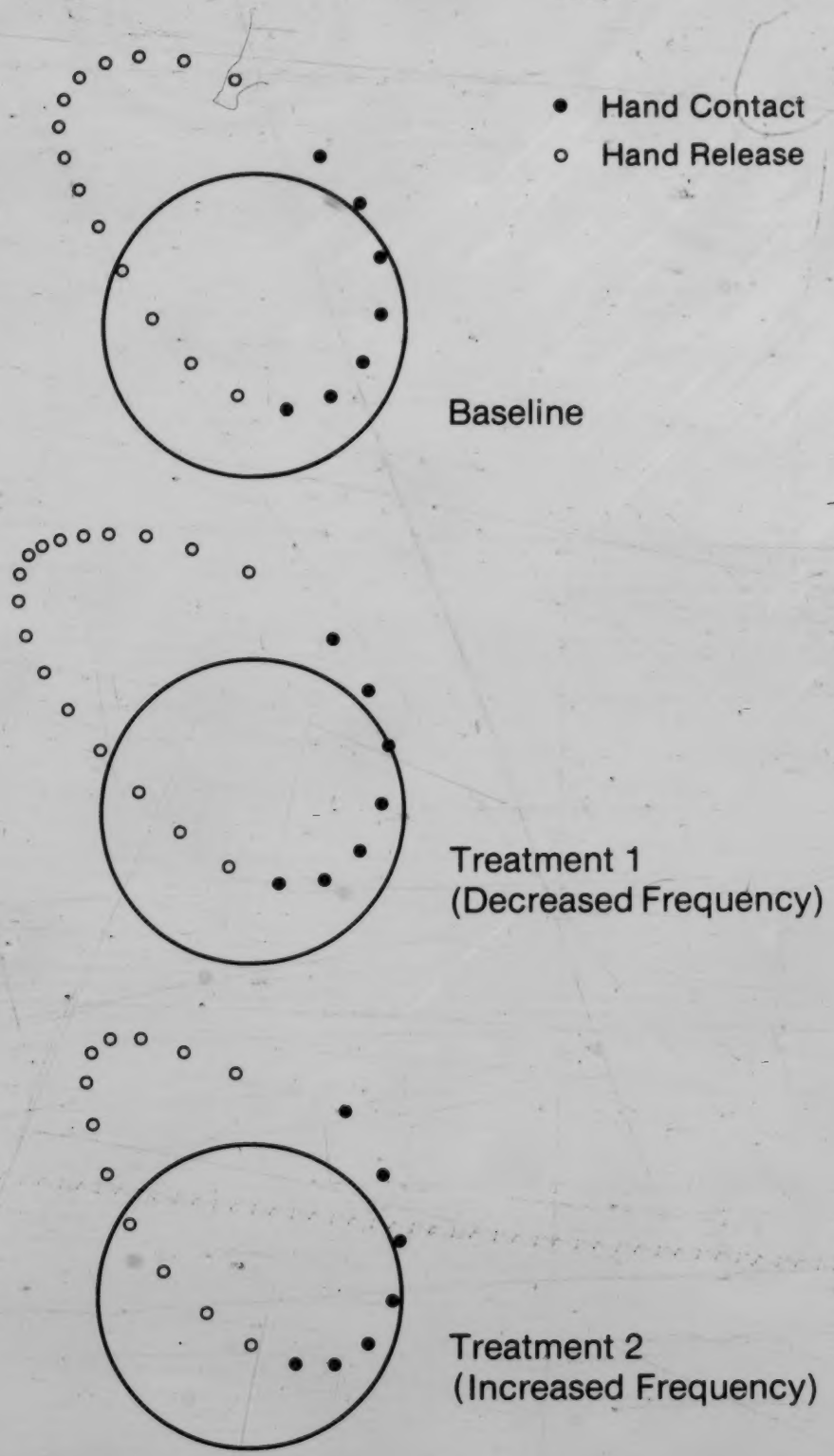


Figure 7. Hand path for subject 5 during three experimental periods.

baseline period. Under decreased pushing frequency conditions however, all subjects moved their hands through a path that was further from the handrim than that of baseline conditions.

Discussion

Just as runners demonstrate a great deal of variability in sprinting technique, the wheelchair subjects who participated in this study displayed large differences in the technique of wheelchair sprinting. These differences may be attributed to such factors as wheelchair design, body structure (eg. arm length, trunk length, hip width) and racing experience.

Under baseline conditions, the average angle of hand contact for the six subjects involved in this study was .09 radians (5.27 deg) while the average angle of hand release was 2.41 radians (138.08 deg). These findings are in disagreement with the results of Higgs (1984) who reported a hand contact angle of -30.84 degrees and a hand release angle of 99.50 degrees. The differences between the angles of hand contact and hand release for this study and that of Higgs (1984) may be attributed to differences in wheelchair design. Recent designs, for example, place the athlete further forward and lower than earlier designs thus moving the contact arc from the top to the front of the handrim. Despite discrepancies in hand contact and hand release

angles, the average contact arcs for this study and that of Higgs (1984) were 132.81 and 130.31 degrees respectively.

While the manner (ie. hand contact angle, hand release angle and contact arc) in which each subject adapted to the two treatment conditions varied, all subjects demonstrated a decrease in pushing length when subjected to an increase in pushing frequency and an increase in pushing length under decreased pushing frequency conditions. Based on the laws of motion, this suggests that as the rate of pushing for each subject decreased, the amount of force that was applied to the handrim during each push increased. These results are in agreement with those of Perrine and Edgerton (1978) and Thorstensson et al. (1976).

These results might lead one to recommend to athletes that, in an effort to achieve maximum velocity, they select a pushing frequency that will allow the greatest force production per push (ie. a slow pushing frequency). This recommendation would be in agreement with the recommendations of Spooren (1981) and Steadward (1979). Results of the timed performances obtained during the three-week experimental period of this study (Figures 4 and 5) suggest however, that such a recommendation may not produce optimum sprinting times.

As explained by Dyson (1973), speed is a product of stride length (pushing length in the case of the wheelchair sprinter) and stride frequency (pushing frequency). Despite

the fact that, in this study, the slower pushing frequencies resulted in the largest pushing lengths, the velocities achieved at these slower frequencies (Table 4) were actually less than (for five out of six subjects) the velocities achieved at the faster frequencies. This implies that the product of the pushing length and pushing frequency is more critical to the attainment of maximum velocity than pushing length alone.

The results of subject 4 (Figure 4) for example, may be explained in terms of this implication. Although during treatment 1, subject 4 demonstrated an increase in pushing frequency, the decrease in pushing length from that of the baseline period, may have been too large to result in an overall improvement in velocity. As explained by Ballreich (1976), an increase in speed can result from a decrease in stride length combined with an increase in stride frequency only if the increase in one component is large enough to counteract the decrease in the other. The results of subject 6, during treatment 1 (Figure 4) may have similarly been faster if the decrease in pushing length had been smaller than that which was demonstrated.

Graphic results of the path of the hand during wheelchair propulsion demonstrate a great deal of wasted arm and hand movement at the slower pushing frequencies. The ultimate purpose in sprinting is to move the wheelchair forward as quickly as possible. According to Hay (1973), the

greater the force, the greater this movement will be. In wheelchair sprinting, any time that the hand is not in contact with the handrim, propulsive forces are not being applied. The goal of the wheelchair sprinter should therefore be to move the hand through the recovery phase as quickly as possible in preparation for the next drive phase.

The results of Figures 6 and 7 show that for both subjects, the quickest recoveries were executed during the periods of increased pushing frequency. These results lend support to the hypothesis that wheelchair sprinters should increase their pushing frequency in an attempt to improve their sprinting speeds.

V. SUMMARY AND CONCLUSIONS

The purpose of this study was to examine the influence of different pushing frequencies on the time required to cover the last 40 metres of the 60-metre wheelchair sprint. The effect of different frequencies on selected kinematic parameters was also examined.

Subjects selected for analysis were three male and three female, elite wheelchair sprinters. A multiple-time-series design using two experimental groups and a cross-over of experimental treatments was used. The experimental time line was divided into pre-baseline, baseline and two treatment periods. The pre-baseline period provided subjects with an opportunity to become accustomed to the new equipment and techniques utilized in the study. During the baseline period, all subjects were required to perform the 60-metre sprint at their preferred pushing frequency. During the first treatment period, group 1 was required to perform at a faster than baseline frequency while group 2 performed at a frequency that was slower than the preferred frequency of the baseline period. The second treatment period was initiated by reversing the treatments administered in the first treatment period.

Temporal data consisted of the time required by each subject to cover the last 40 metres, and every 10-metre

segment within that distance, of a 60-metre indoor sprint during the baseline and two treatment periods. This was measured by means of a series of retroreflective controls.

Cinematographical data were collected from a field width of 10 metres utilizing a panning technique. Data collection occurred on the final day of the baseline and each of the two treatment periods. The sprinting performance of each subject was filmed in an effort to quantify the point of hand contact, the point of hand release, the magnitude of the contact arc, the pushing length and the path of the hand during the propulsion cycle under baseline, treatment 1 and treatment 2 conditions.

Results of this study showed a gradual decrease in the time required by wheelchair sprinters to cover each successive 10-metre segment of the 40-metre distance. These results agreed with those reported for stand-up sprinters (Woicik, 1983).

While the overall results of the temporal analysis suggested that frequency had no effect on the timed performances of the six athletes who participated in this study, an analysis of the individual performances provided support for the hypothesis that increased pushing frequency would result in increased sprinting velocities.

Results of the cinematographical analysis showed that each subject responded to the variations in pushing frequency in a different manner. It was shown however, that

the two treatments administered over the course of this study did have an effect on the distance travelled by the wheelchair as a result of one push on the handrim (pushing length). More specifically, the wheelchair sprinters demonstrated longer pushing lengths at the slower pushing frequency and shorter pushing lengths at the faster pushing frequency.

The two treatments similarly had an effect on the path of the hand during the recovery phase of the propulsion cycle. While the slower pushing frequency resulted in a hand path that moved away from the handrim and displayed much unproductive movement, the hand remained in close proximity to the handrim at the faster pushing frequency.

Within the limitations of this study, the results obtained during the experimental period led to the following conclusions:

1. Wheelchair sprinters demonstrated the same pattern of peak velocity attainment as stand-up sprinters.
2. Maximum velocity in wheelchair sprinting was directly related to maximum force production and was best achieved through a technique whereby athletes exhibited a fast pushing frequency and a short pushing length.
3. An incorrect balance between pushing frequency and pushing length was mainly responsible for poor sprinting performances.

4. Wheelchair sprinting techniques were varied and appeared to be influenced by the design of the wheelchair, the body structure of the athlete and racing experience.
5. Based on the variability and overlap in the scores displayed by some of the subjects during the three experimental periods of this study, it was concluded that the length of the treatment periods was insufficient to produce the desired effect.
6. Comments offered by two of the subjects suggested that the faster frequency was very difficult to attain. This led to the conclusion that for these subjects, increases of 11.11% in pushing frequency over their preferred frequency were too large.
7. The cinematographical methods employed in this study produced information that for kinematic analysis, was sufficiently valid and reliable.

The results of this study have led to the following recommendations:

1. When attempting to increase the pushing frequency of wheelchair sprinters, coaches should allow sufficient time for the athletes to adapt to the treatment. An awareness of the differences in learning rates between athletes should also be present.
2. While it has been shown that increased pushing

frequencies can produce improved sprinting times, the magnitude of these frequency increases should be individually prescribed for each athlete. Further research is required in order to determine an appropriate method for selecting the ideal pushing frequency for each athlete.

3. In an effort to increase the pushing frequency of wheelchair sprinters, coaches should instruct their athletes to execute the recovery phase as quickly as possible. This may be achieved by keeping the hands in close proximity to the handrims throughout the recovery phase.
4. The use of a metronome as an aid to increasing pushing frequency in wheelchair sprinting is recommended.
5. This study should be replicated using less experienced athletes.
6. This study should be replicated using longer experimental periods to allow for sufficient adaptation to the various pushing frequencies.
7. The study should also be replicated using three-dimensional cinematography to allow for better identification of hand contact and hand release points.
8. A comprehensive study of force application during the different phases of the wheelchair propulsion cycle is needed.
9. An analysis of sprinting velocities over a 100-metre

distance should be conducted in an effort to determine the occurence of peak velocities for wheelchair sprinters at this distance.

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APPENDIX A

INFORMED CONSENT FORM

Thank you for agreeing to take part in this study. Please note that your participation is entirely voluntary and that you are free to withdraw yourself as a subject at any time during the course of the experiment.

The purpose of this study is to investigate the influence of different pushing frequencies on the time required to cover the 60-metre wheelchair sprint.

You will be requested to submit to the following procedures:

1. Pre-training familiarization
2. Video analysis
3. Training
4. Cinematographical analysis

During the pre-training familiarization period, you will be given an opportunity to become familiar with utilizing 13" X 5/8" handrims and also wheeling in time with a metronome.

The video analysis will be carried out in an effort to determine your average pushing frequency. During this session, you will be required to perform three repetitions of the 60-metre sprint with a three-minute recovery between trials.

In total, you will be required to train for 15 days. Each training day will begin with a standard warm-up routine followed by five repetitions of the 60-metre sprint. During

each training session, your pushing frequency will be monitored and controlled by means of a battery-operated metronome.

Cinematographical analyses will take place at the conclusion of each five-day training session. Once again, you will be required to perform three repetitions of the 60-metre sprint with a three-minute recovery between trials.

The investigator will be present at all data collection sessions and will answer any inquiries you may have concerning the procedures. At the conclusion of the study, the results will be made available for your review.

Participation in this study is contingent upon the signed consent of each subject. Therefore, please read the statement below and sign in the appropriate space.

I have read and understand the procedures of the above-described study. I agree to participate as a subject in all phases of the study. I also agree to allow any data taken of me in this study to be used in professional presentations and publications provided my identity remains anonymous.

Name:_____

Signature:_____

Date:_____

APPENDIX B

WHEELCHAIR SPRINTING QUESTIONNAIRE

NAME:_____
DATE:_____

1. Which frequency (week 1, 2 or 3) felt the most natural?

2. During which week (1, 2 or 3) do you feel you achieved your fastest times?

3. During which week (1, 2 or 3) do you feel you achieved your slowest times?

4. Did you experience any problems during week 1? (i.e. couldn't maintain the frequency, frequency too slow or too fast, couldn't execute enough force, etc.)

5. Did you experience any problems during week 2?

6. Did you experience any problems during week 3?

7. Did you consciously do anything to adapt to the frequency implemented during week 1?

8. Did you consciously do anything to adapt to the frequency implemented during week 2?

9. Did you consciously do anything to adapt to the frequency implemented during week 3?

10. Any other comments?